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May 1990

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Special Report 90-15

U.S. Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Multiband Imaging Systems

Harlan L. McKim, Carolyn J. Merry and Nancy T. LaPotin

May 1990

Prepared for
OFFICE OF THE CHIEF OF ENGINEERS

PREFACE

This report was prepared by Dr. Harlan L. McKim, Research Physical Scientist, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory, Dr. Carolyn J. Merry, Assistant Professor, Department of Civil Engineering, Ohio State University, and Nancy T. LaPotin, Physical Science Technician, Geological Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory. Funding was provided by DA Project 4A762784AT42, *Cold Regions Engineering Technology*; Work Unit CS/022, *Winter Battlefield Terrain Sensors*. This paper was prepared at CRREL in support of the Engineer School, specifically the Multiband Imagery Panel, and the operational and organizational plan *Multiband Collection and Analysis System* (MCAS) for clarification of the capabilities and availability of existing satellite imagery.

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Multiband Imaging Systems

HARLAN L. MCKIM, CAROLYN J. MERRY AND NANCY T. LAPOTIN

INTRODUCTION

On today's high-tech battlefield, military commanders need accurate and timely terrain information to defeat the enemy. U.S. Army doctrine dictates that every unit must be prepared to fight and win, even if outnumbered. To lessen the disadvantage of fighting against an enemy whose numbers may be three times ours, the armed forces must rely on superior weapon systems and on the best information systems available.

Intelligence from satellites or other airborne platforms can give units on the battlefield an insurmountable advantage over the enemy. When multiband data from these devices are placed into a geographic information system, the results can vividly convey tactical information to the commander by providing an image backdrop to other attribute data, such as soil type, vegetative cover and slope. Geographic information systems can display both terrain analysis data, such as high resolution photographs, and multispectral data, such as thermal, radar or IR imagery.

Multiband imaging is the simultaneous acquisition of remotely sensed data for the same ground locality at different wavelengths. The different wavelengths provide an opportunity for the photo interpreter or the image analyst to distinguish many surface features, depending upon the wavelengths used. In the field of digital image processing, multiband information forms the data set for multispectral classification techniques that the analyst uses to create thematic overlay maps of earth surface features, such as land cover, road networks and the extent of a snow cover. This information is available through various commercial systems and remains untapped by the field Army. This paper, intended for the terrain analysis community, will describe existing and future multiband imaging systems and the potential they have for improving routine terrain analysis efforts.

DESCRIPTION OF MULTIBAND IMAGING TECHNIQUES

Today, virtually all commercial satellites acquire multispectral image data by means of scanners. Multiband scanners can be categorized as being either passive or active. These instruments detect the electromagnetic energy that is reflected or radiated from the surface features. The source of the illuminating radiation for passive systems is external, such as the sun or the surface features themselves. The Landsat sensors are examples of passive multiband remote sensing systems.

Active remote sensing systems have their own electromagnetic energy source. The device illuminates the target using its own energy, detects the energy reflected from the surface and records the incoming data as a digital number (usually 0–255). Radar is an active form of remote sensing that operates in the microwave and radio wavelength regions. The Side-Looking Airborne Radar (SLAR), developed in the 1950's to acquire reconnaissance images, is one example of an active remote sensing system.

In commercial applications, once the data from either an active or passive system are recorded, they are stored in digital format on magnetic tape. The digital information can then be displayed by an image processing system for analysis. The data set is in a scan line and pixel location format and thus forms a multidimensional spatial data base. This spatial data base can be geometrically corrected to a specified scale. Another option is to place the processed multiband data into a Geographic Information System (GIS). A fully functional GIS is capable of four kinds of operations: data input, data storage, data analysis and data output. The thematic overlay files, such as soils and elevation, can be digitized and added to the GIS. The utility of multiband data may be further enhanced by merging with demographic data files, such as

TIGER (Topologically Integrated Geographic Encoding and Referencing) files available from the U.S. Census Bureau.

EXISTING MULTIBAND IMAGING SYSTEMS

Landsat

The U.S. Landsat series of satellites are multiband imaging scanner devices that record emitted and reflected electromagnetic energy in specific wavelengths or bands.* The first Landsat satellite was launched in July 1972. Two sensors, the Multispectral Scanner Subsystem (MSS) and the Thematic Mapper (TM), are on the present Landsat-4 and -5 satellites. The near-polar, sun-synchronous orbit of Landsat allows the satellite to image the same area on the ground every 16 days. The satellites were previously owned and operated by the U.S. Government, but ownership was transferred to a private company, EOSAT (Earth Observation Satellite Company), in 1985. Ownership was transferred after the Land Remote Sensing Commercialization Act of 1984.

The MSS, the first sensor developed for use on the Landsat satellite, records data in two visible bands and two reflected near infrared (IR) bands (Table 1). The MSS is a mechanical line scanner

Table 1. Wavelength coverage for the Landsat MSS sensor.

MSS band	*Wavelength (μm)*	*Portion of electromagnetic spectrum*
1	0.5–0.6	Visible green
2	0.6–0.7	Visible red
3	0.7–0.8	Near IR
4	0.8–1.1	Near IR

that obtains data for six scanlines in one sweep of the oscillating scan mirror. The MSS data have a ground pixel resolution of 80 m and are particularly useful in delineating large-scale geologic, vegetative or agricultural features. A Landsat MSS scene contains information for approximately 185 × 185 km on the ground.

The wavelengths were selected by scientists at NASA and the U.S. Geological Survey (USGS), and approximate the wavelengths covered by color IR photography. Any three of the multispectral bands may be registered and projected in red, green and blue to produce a color composite image.

The TM is the most recent sensor on the Landsat series of satellites and records data in three visible bands, one reflected near IR band, two reflected middle IR bands and one emitted thermal IR band (Table 2). The TM is also a mechanical line scanner,

Table 2. Wavelength coverage for the Landsat TM sensor.

TM band	*Wavelength (μm)*	*Portion of electromagnetic spectrum*
1	0.45–0.52	Visible blue
2	0.52–0.60	Visible green
3	0.63–0.69	Visible red
4	0.76–0.90	Near IR
5	1.55–1.75	Middle IR
6	10.40–12.50	Thermal IR
7	2.08–2.35	Middle IR

but scans and obtains data during both sweeps of the oscillating scan mirror. The additional bands are aimed at improving agricultural and geological applications of the data and for monitoring water quality.

The TM data have a ground resolution of 30 m, which is a significant improvement over the MSS data. In addition to the increase in the number of spectral bands, the TM also has an increased radiometric sensitivity. The range of radiometric levels (gray scale levels) that can be detected has been increased from 64 in the Landsat MSS data (6-bit data) to the TM's 256 (8-bit data).

The addition of TM band 1 (visible blue) enables the maximum penetration of water and permits bathymetric mapping in shallow water with low turbidity. TM band 1 is also useful in distinguishing soil from vegetation. TM band 1 has no MSS equivalent.

TM band 2 (visible green) includes the green reflectance peaks of vegetation and so provides a basis for assessing plant vigor. MSS band 1 covers approximately the same spectral range.

TM band 3 (visible red) is useful in discriminating between some vegetative classes by including a chlorophyll absorption band. The visible wavelength bands are best for defining the presence of snow and forest canopy cover. MSS band 2 covers approximately the same spectral range.

Water can best be separated from other cover types using data collected in either the near or middle IR wavelengths. The wavelengths in TM band 4 (near IR) include a water absorption band

* Lillesand, T.M. and R.W. Kiefer (1987) *Remote Sensing and Image Interpretation*, 2nd ed. New York: John Wiley and Sons, Inc.

and are therefore useful for mapping vegetative wetlands (differentiating among various vegetative species and conditions) and for shoreline analysis (water has a very low reflectivity in comparison to vegetation and land in band 4). The near IR wavelengths are also useful for delineating areas of snow cover. MSS bands 3 and 4 cover a portion of the near IR range of TM band 4.

TM band 5 (middle IR) gives excellent contrast between vegetative cover types and is also useful for estimating the moisture content of both soil and vegetation. TM bands 5 and 7 can be used to distinguish between clouds and snow cover. There is no MSS band equivalent.

TM band 6 (thermal IR) is useful for thermal mapping. The thermal IR region can be used to discriminate differences in water temperature, such as those found downstream from discharge outlets of nuclear or fossil fuel power plants or other industrial plants. Thermal IR often is useful for mapping changes in surface soil moisture and for energy loss problems. There is no MSS band equivalent.

TM band 7 (middle IR) coincides with an absorption band caused by hydroxyl ions in minerals. Ratios of TM bands 5 and 7 are useful in mapping hydrothermally altered rocks associated with mineral deposits because of the presence of clay minerals that contain hydroxyl. There is no MSS band equivalent.

SPOT satellite system

The SPOT satellite was launched in February 1986 by the French government in association with its European partners, Belgium and Sweden. The satellite operates in two spatial resolution modes—20 and 10 m. In the 20-m multispectral mode, data are collected in two visible bands and one near IR band. In the 10-m panchromatic mode, the satellite images over a wider spectral region and provides excellent spatial resolution. The SPOT satellite is in a near-polar, sun-synchronous orbit at an altitude of 832 km. The orbital cycle is 26 days. The data are of high radiometric quality with 8-bit data for 256 radiometric levels. Table 3 provides a listing of the wavelength region covered by each band of the SPOT satellite.

Table 3. Wavelength coverage for the SPOT HRV sensor.

SPOT band	*Wavelength (μm)*	*Portion of electromagnetic spectrum*
XS1	0.50–0.59	Visible green
XS2	0.61–0.68	Visible red
XS3	0.79–0.89	Near IR
Panchromatic	0.51–0.73	Visible–Near IR

The satellite contains two HRV (High Resolution Visible) scanning devices The HRV is a "pushbroom" scanner, which means it obtains the data instantaneously along each scanline. When the satellite is at nadir, the two HRV's each image a 60-km width. There is a 3-km overlap in the center so the total image width is 117 km.

SPOT is the first satellite that can point from nadir at 0.6 increments up to a maximum of 27 on either side of the orbital path. The satellite can thus image any area within a 950-km swath centered over an orbital path. This allows for the acquisition of stereo imagery and for more revisit opportunities over an area of interest. For example, at a latitude of 42 north (CRREL, Hanover, New Hampshire), the sensor could image the area 11 times during the 26-day orbital path. A maximum of six stereopairs can also be obtained during the 26-day cycle.

AVHRR satellite systems

When large-scale or high-resolution multiband data do not supply the areal coverage required for global monitoring or modeling, the NOAA AVHRR (Advanced Very High Resolution Radiometer) digital data can be used. The imaging system is a multiband scanner that acquires images with a swath width of 2700 km and a ground resolution of 1.1 km. Local Area Coverage (LAC) data are available at the 1.1-km resolution or Global Area Coverage (GAC) or 4-km data, derived from the LAC data, can be obtained. The AVHRR sensor obtains data in one visible band, one near IR band, one middle IR band and two thermal bands. Table 4 provides a listing of the multiband coverage provided by the AVHRR sensor.

Table 4. Wavelength coverage for the AVHRR sensor.

AVHRR band	*Wavelength (μm)*	*Portion of electromagnetic spectrum*
1	0.55–0.68	Visible red
2	0.73–1.10	Near IR
3	3.55–3.93	Middle IR
4	10.50–11.50	Thermal IR
5	11.50–12.50	Thermal IR

The NOAA-6 and NOAA-9 satellites are polar-orbiting satellites. NOAA-6, launched in June 1979,

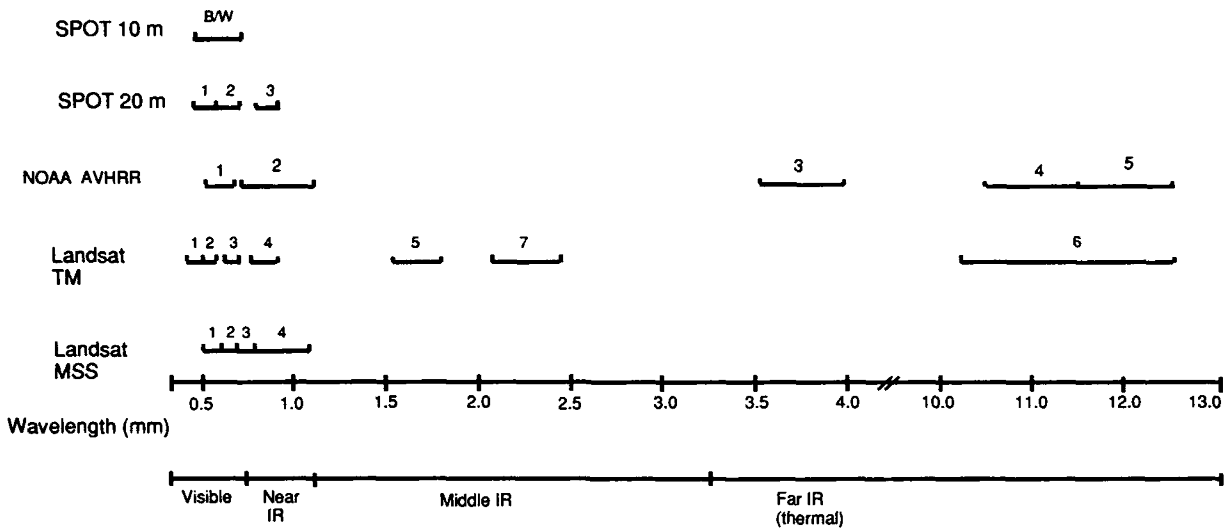

Figure 1. Spectral band wavelengths covered by satellite sensors.

is at an altitude of 806 km and NOAA-9, launched in November 1984, is at an altitude of 863 km. The AVHRR data are acquired every 12 hours to provide day and night coverage. The sensor acquires 10-bit data resulting in 1024 gray levels.

The spectral ranges of AVHRR bands 1 and 2 were selected for vegetation mapping. Band 1 is approximately equivalent to band 3 of the Landsat TM. AVHRR band 2, which is in the near IR region, is approximately equivalent to TM band 4. Water bodies are clearly distinguishable from land in this wavelength region, because of the low reflectance values of water compared to the high reflectance values of vegetation. AVHRR band 4 is a daytime thermal IR equivalent to TM band 6. High reflective values represent relatively high radiant temperatures and low reflective values represent relatively low radiant temperatures. AVHRR images are well suited for studying vegetation distribution and seasonal changes on a continental scale.

Figure 1 is a diagram showing the spectral band wavelength coverage for the passive multiband imaging systems described.

Japan (MOS-1)

The Japanese MOS-1 (Marine Observation Satellite) was launched in February 1987. The satellite payload includes two optical sensors and a microwave sensor for looking at the ocean. The MESSR (Multispectral Electronic Self-Scanning Radiometer) is a four-band (0.51–0.59, 0.61–0.69, 0.72–0.80 and 0.80–1.1 µm) linear array of Charge Coupled Devices (CCD) and is capable of collecting spectral data in the visible and near IR at a ground resolution of 45 m. MESSR has a quantization level of 64 (six bits).

MOS-1 also carries a Visible and Thermal Infrared Radiometer (VTIR) to measure sea surface temperature and cloud cover. This is a mechanical scanner with a 15-cm aperture radiometer. There is one visible band (0.5–0.7 µm) with a 90-m spatial resolution and three IR bands (6–7, 10.5–11.5 and 11.5–12.5 µm) imaging a 1500-km swath.

A Microwave Scanning Radiometer (MSR) is also on board and has two frequencies: 23.8 GHz for a 40-km resolution (2-beam width) and 31.4 GHz for a 30-km resolution (1.5-beam width). This sensor measures atmospheric water content, snow, ice and sea surface conditions.

India (IRS-1)

The Indian Space Research Organization launched a remote sensing satellite (IRS-1) in March 1988. IRS-1 orbits the earth in a polar, sun-synchronous orbit at 904 km. The spacecraft's two sensors provide multispectral coverage in the visible and near IR wavelengths at 73- and 36.5-m resolution. These data will be made available as film and computer compatible tapes for use in agriculture, hydrology, geology and forestry.

Radar imaging systems

A radar imaging system is an example of an active multiband imaging device. The radar bands most commonly used in the field of remote sensing are shown in Table 5. Only the K and X band imaging radars are commercially available. Radar data are used primarily in the fields of snow and ice

Table 5. Radar bands commonly used in remote sensing.

Band designation	*Wavelength (cm)*	*Frequency (GHz)*
Ka	0.83–1.40	36.00–22.00
Ku	1.40–2.80	22.00–10.90
X	2.80–5.20	10.90–5.75
C	5.20–7.10	5.75–4.20
S	7.10–19.40	4.20–1.55
L	19.40–76.90	1.55–0.39
P	76.90–133.30	0.39–0.225

mapping, sea ice monitoring and soil moisture measurement. Active devices can be a more reliable source of remote sensing information than passive devices because images can be acquired during the day or night and are not affected by cloud coverage.

The SLAR and the SAR (Synthetic Aperture Radar) are two examples of active multiband imaging devices. Airborne platforms, orbiting satellites and the space shuttle are all vehicles from which SAR imagery has been obtained.

EXAMPLES OF THE USE OF MULTIBAND IMAGERY

Color composite imagery, made using multispectral data, allows the image analyst to view three bands of data simultaneously. Any three of the multispectral gray scale images may be registered and projected in the additive primary colors (blue, green and red) to produce an image. The spectral band combinations used in the color composite are selected according to the features in the image that are to be emphasized. For example, a "false color" composite—a visible band displayed in the blue gun of the color display monitor (TM band 2), a visible band in the green gun (TM band 3) and a near IR band in the red gun (TM band 4)—is typically created when information about vegetation is needed. A "true color" composite—a visible band in the blue gun (TM band 1), a visible band in the green gun (TM band 2) and a visible band in the red gun (TM band 3)—produces an image whose colors more closely resemble the colors as they would appear to an analyst. Subtle changes or highlights observed on composite images may provide valuable insight to the analyst.

The following set of examples has been compiled to show how multiband imagery may be used to extract certain types of terrain feature information. In Figure 2, color composites of Landsat MSS and TM and SPOT imagery are presented. It is important that the reader understands that the colors shown on Figure 2 were selected by the interpreter and can be changed. In addition, identification of individual features is often based on the experience of the interpreter, whose ability to use his or her knowledge makes for the best use of multiband imagery.

Figure 2a shows a color combination of a statistical analysis performed on TM multispectral imagery. The combination in this case emphasizes the discrimination between vegetation (shown in green and red) and water (shown in yellow). This image gives the interpreter the ability to map areas of open water, wet areas (shown as darker tones of green and red) and dry areas (shown as lighter tones) for operational planning in a denied area. New roads, shown as white, linear features, and construction activity, shown as irregular, white features, can also be detected.

The large, linear, white feature in the northwest portion of the image is an airport. The length and width of the runways and its overall plan were the features that identified this as an airport. The interpreter can infer other intelligence information around the airfield from the image. What appears to be a storage area can be seen near areas 2 and 3. Vegetative stress can also be seen in the area near 2. Stressed vegetation near storage areas appears as light green, whereas the less stressed vegetation appears darker. Healthy vegetation can be seen as the red patches scattered throughout the image. Because of its proximity to the airfield, and the stressed appearance of the nearby vegetation, storage area 2 probably contains fuel or ammunition.

Figure 2b is a close-up of the airfield and the storage area located near area 2 in Figure 2a. This is a false-color composite made using TM bands 2, 3 and 4 (blue, green and red respectively). The linear feature that surrounds the storage area is a fence. The airfield runway is being extended, as indicated by the bright white area to the southwest of 1.

Figure 2c is also a false-color composite made using TM bands 2, 3 and 4. It is an enlargement of another storage area that supports the airfield. We can see the white, rectangular, linear feature, which is probably a fence around the storage area. The open, bright circular features within the fenced area indicate construction of new storage facilities. The less bright, smaller circular features are older fuel or ammunition facilities. We see evidence of a fence around the entire compound in the circular

trace, caused in part by a change in the reflectance in vegetation around most of the facility. Below the storage area and running in an east–west direction, we see three long, white lines. Because of the length and size of the features and their proximity to the airport, we interpret these to be a railroad track, an oil pipeline and a highway right of way (4 in Fig. 2c).

Using one digital satellite image, we can identify many features of importance to engineers and intelligence people. We can quickly observe and inspect an area of 26,000 km^2. Enlargements of specific portions of the image can reveal greater detail, as shown in the above examples.

A SPOT multispectral data set gives another example of the use of satellite data. Figure 2d is a false color composite of a SPOT image made using bands 1, 2 and 3 (blue, green and red). The scale of the image is 1:50,000. In this example we were interested in the airfields. It was possible to discriminate these features using the SPOT data set. An airfield is clearly seen in the center of the image. Knowing that each pixel is 20 m, we easily calculated the airfield length to be approximately 2.5 km.

Figure 2e is a map produced from an unsupervised classification of the data shown in Figure 2d. We did the unsupervised classification having no prior knowledge of the area. This example shows how land use can be mapped over large areas in a very short time (can be less than 24 hours). Each color on the classification map represents an area whose spectral characteristics are approximately the same in all three bands. For example, the vegetated highlands, shown in red, have a high spectral value in the near IR band, as determined from a histogram of the gray values recorded for each band (band 3). In contrast to the vegetated highlands, the water pixels, shown in orange, are very low in the near IR band. This difference is to be expected, because in the near IR, vegetation has a much higher reflectance than water. Water absorbs most of the radiation and reflects very little back to the sensor and thus appears black. The blue areas of the classification map appear to be highlands with a lesser amount of forest cover. The yellow and gray areas appear to be the hill slopes adjacent to the valleys, and marsh and low lying areas are indicated by the green color. The town areas and, to a lesser degree, the road networks are shown in pink. It is interesting to note that, in this case, the airfield runways form a distinct class; this may prove useful in quickly locating other airfields in larger areas.

Figure 2f shows a portion of a high density urban area. These SPOT data are of sufficient spatial resolution for street patterns to be visible. Comparison of this image with the latest 1:50,000 topographic map (1978) revealed considerable change. Five structures crossing the river are visible—one bridge across the lower mid-stream island, two bridges between the two islands and two structures across the upper mid-stream island. These last two structures did not appear on the 1978 topographic map. In addition, several smaller structures jutting into the river were constructed in the river bend. Figure 2g is an enlargement of the area. The two new structures are seen to be discontinuous across the river and may be jetties or groins, but it is difficult to confirm the type of structure. There has been intense urbanization of the area inside the river bend.

Figure 2h shows a rural airstrip in a small river valley. The airstrip facility has been substantially upgraded since publication of the 1978 topographic map. We calculated that the runway was approximately 3460 m long and that the entire facility occupies approximately 8.5 km^2. The major changes to the facility are the addition of the main taxiway (east of the runway centerline), reconfiguration of the parking facility and paving of most access roads to the facility.

Figure 2i is an enlargement of a similar airport facility, in which we detected little change since the 1976 topographic map of the area was prepared. In this view tire marks, which are produced during aircraft landings, are visible as dark, bluish stripes on the runway at the southeast end. Tire marks are noticeably absent from the northwest end of the strip, indicating that landings at this facility are made primarily from a southeast to northwest direction. The runway was calculated to be approximately 2470 m long.

Figure 2j shows a coastal area at the mouth of a river. The rectangular shaped terrain features to the south of the river are the beds of a salt evaporator and are also shown on the 1976 map of the area. Development north of the river is apparent and consists primarily of intense agriculture. Approximately 2 km^2 of land area has been claimed by diking of the low-lying riverbank and coastline areas. The prominent jetty (830 m long) in the left central part of the image has also been recently constructed. The structure may be an attempt to control sediment patterns near the river mouth. Sedimentation and current patterns are also visible. They appear as the lighter tonal patterns in the water.

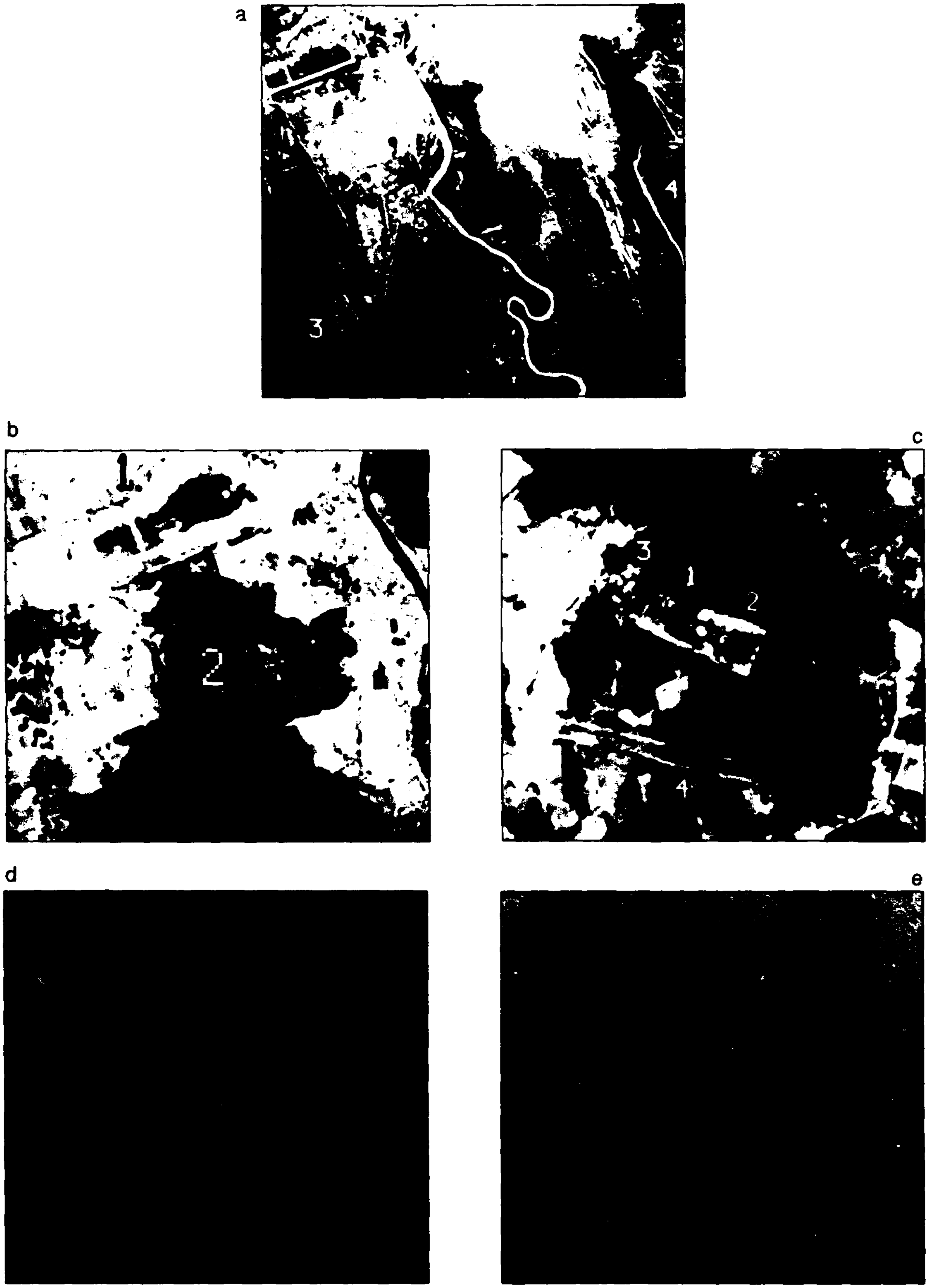

Figure 2. Color composites of Landsat TM and MSS and SPOT imagery.

f

g

h

i

j

Figure 2 (cont'd). Color composites of Landsat TM and MSS and SPOT imagery.

FUTURE SATELLITE SYSTEMS

USA (Landsat-6, -7)

The service life of Landsat-5 was projected to end in December 1989. Landsat-6 is scheduled to be launched in June 1991. The primary new sensor will be the Enhanced Thematic Mapper (ETM). The ETM will offer co-registered 15-m panchromatic and 30-m multispectral (7 band) data.

The sensors for future Landsats will include the ETM data with increased thermal IR capabilities. In addition, a Sea Wide Field Sensor (SeaWiFS) instrument will contain eight co-registered spectral bands in the visible, near IR and thermal IR. SeaWiFS will also provide wide area coverage, a spatial resolution of 1.13 km and a daily repeat cycle.

In addition, EOSAT is investigating adding a 5-m resolution, full color Satellite Tracking and Reporting sensor (STAR), an expanded wide-field land and SeaWiFS coverage and a rapid revisit Advanced Landsat Sensor (ALS). The ALS will be a pointable system and will provide an opportunity to obtain high resolution data from a 40-km swath. A small SAR radar system is also planned.

France (SPOT-2, -3, -4)

The SPOT-2 satellite will be identical to SPOT-1 and is ready for launch; however, the launch of SPOT-2 will depend on the performance of SPOT-1. SPOT-3 will be identical to SPOT-2 and will be ready for launch in the first quarter of 1992. The first three SPOT satellites have a designed lifetime of about 3 years. The SPOT-4 satellite will have a new design and will be ready for launch in the beginning of 1995. SPOT-5 will be identical to SPOT-4, and will be ready for launch in 1999.

The design for SPOT-4 includes a new vegetation sensor. This instrument is similar to the NOAA AVHRR sensor and will include two bands: a middle IR (1.50–1.75 µm) and a visible (0.43–0.52 µm). The instrument is pointable to ± 50 and will provide daily coverage at a 1.2-km resolution for an image width of 2200 km. SPOT should produce vegetation index maps every week to 10 days at a 4-km resolution (2x2 pixels). The present three-band multispectral HRV (20-m resolution) will also contain the middle IR band for the SPOT-4 and -5 satellites. The projected life expectancy for the SPOT-4 and -5 satellites is 4 years.

European Space Agency (ERS-1)

The Earth Resources Satellite is scheduled for launch by the European Space Agency in early 1992 and will include a set of active microwave sensors. It will be in a sun-synchronous orbit at an altitude of 785 km with a 3-day repeat cycle. The first of the two main instruments is an Active Microwave Instrumentation (AMI) package, which operates in the C-band (5.3 GHz) and combines the functions of a SAR, a wave scatterometer and a wind scatterometer. The capabilities of the AMI will be used to measure the wind field and the wave spectrum over oceans, and to take all-weather, high resolution images over polar caps, coastal zones and land areas. The resolution of the SAR will be 30 m in an 80-km swath.

The second main instrument is the Radar Altimeter (RA), operating in the Ku band (13.7 GHz) and pointing at nadir. The RA measures spacecraft altitude, from which significant wave height, ocean surface wind speed and various ice parameters can be determined. Additional instruments include an Along-Track Scanning Radiometer and Microwave sounder (ATSR/M), which is an IR imaging sensor combined with a nadir-looking microwave sensor for measuring sea-surface temperature, cloud-top temperature, cloud cover and atmospheric water-vapor content. A Precise Range and Rate Equipment (PRARE) instrument will allow a significant upgrading of the altimetry mission by providing a precise satellite range determination. This will lead to higher accuracy altitude measurements that will extend the ERS-1 mission to ocean circulation studies and geodetic applications, such as sea-surface topography and crustal dynamics. A Laser Retro-Reflector (LRR) is a passive optical device that will allow accurate satellite tracking from the ground to support instrument data evaluation.

Canada (Radarsat)

The launch of a radar satellite is scheduled for 1994 by the Canada Centre for Remote Sensing, in cooperation with NASA. The satellite will be in a sun-synchronous orbit. The sensor on Radarsat is a Synthetic Aperture Radar (SAR) with a C-band (5.3 GHz) movable beam. The resolution will be 25 to 30 m for a 500-km image swath. The sensor will be used for monitoring ice conditions in the polar seas. Two or three satellites might eventually be in orbit simultaneously.

CONCLUSION

This paper has described the existing and planned satellite systems capable of collecting

multispectral data that are available to the public. Satellite multispectral information could be a tremendous asset to Army commanders for planning all phases of military operations. The imagery may provide critical, up to date information on enemy lines of communication, troop concentrations, road and airfield networks, water supplies, terrain elevation, vegetation types and river crossing opportunities. This available technology will be further enhanced by future artificial intelligence software developments, providing immediate interpretation of significant terrain feature patterns or spectral signatures.

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13. ABSTRACT (*Maximum 200 words*)

Digital data from satellite systems can provide timely and detailed terrain information for battlefield intelligence. Multiband imaging systems that can acquire simultaneous remotely sensed data for the same ground locality throughout the electromagnetic spectrum are available for analysis using conventional photo interpretation techniques or more sophisticated digital image processing methods. This report describes existing and future multiband imaging systems with the emphasis on how a terrain analyst would use these data to prepare thematic overlays.

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